DELIVERABLE D 3.4

AGILE 4.0 ASSESSMENT

Author(s): T. Lefebvre
WorkPackage N°: WP3
Due date of deliverable: 31.12.2022
Actual submission date: 31.04.2023
Document ID: AGILE4_D3.4.docx

Grant Agreement number: 815122
Project acronym: AGILE 4.0
Project title: Towards cyber-physical collaborative aircraft development
Start date of the project: 01/09/2019
Duration: 42 months

Project coordinator name & organisation:
Luca Boggero
DLR – System Architectures in Aeronautics | Aircraft Design and System Integration
Tel: +49 40 2489641-338
E-mail: luca.boggero@dlr.de

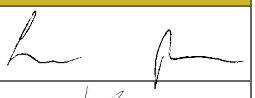
Project website address: www.agile4.eu

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION'S HORIZON 2020 RESEARCH AND INNOVATION FRAMEWORK PROGRAMME UNDER GRANT AGREEMENT NO 815122

DOCUMENT INFORMATION

Document ID	AGILE4.0_Deliverable_D3.4_v0.4.docx		
Version	0.4		
Version Date	05/04/2023		
Author	T. Lefebvre		
Dissemination level	PU		

APPROVALS

	Name	Company	Date	Visa
Coordinator	L. Boggero	DLR		
WP Leader	T. Lefebvre	ONERA		

DOCUMENTS HISTORY

Version	Date	Modification	Authors
0.1	03/01/2022	Creation	T. Lefebvre
0.2	15/01/2022	Add effectiveness metrics	T. Lefebvre
0.3	24/03/2023	First complete version	T. Lefebvre
0.4	05/04/2023	Conclusion added	T. Lefebvre

LIST OF AUTHORS

Full Name	Organisation
T. Lefebvre	ONERA

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GLOSSARY

Acronym	Signification
AC	Application Case
EMC	Electro-Magnetic Compatibility
MDA	Multidisciplinary Design Analysis
MDF	Multidisciplinary Design Feasible
MDO	Multidisciplinary Design Optimization
OCE	Operational Collaborative Environment
RCE	Remote Component Environment
RSM	Surrogate Model
XDSM	Extended Design Structure Matrix

1 EXECUTIVE SUMMARY

1.1 Introduction

In the frame of AGILE 4.0 project, WP3 is responsible for the optimization and validation phase. The activities to be conducted can be grouped under three different objectives:

- finalize digitalization & modeling guidelines in order to accelerate, streamline and improve the design, manufacturing, certification and operation of Systems of Interest.
- support the optimization process of Systems of Interest
- assess the project achievements at both Systems of Interest and Development System levels

This deliverable describes the results of the activities performed under last objective, specifically the assessment activities of AGILE 4.0 technologies and Application Cases

1.2 Brief description of the work performed and results achieved

In this deliverable D3.4, the main activities related to the assessment activities of AGILE 4.0 technologies and Application Cases are reported.

1.3 Deviation from the original objectives

1.3.1 Description of the deviation

This deliverable release has experienced a 2-month delay.

1.3.2 Corrective actions

As the WP3 “assessment” activities were highly dependent of Applications Cases finalisation, especially for some dedicated metrics some mitigation process was applied. Therefore, a significant part of the metrics was collected all along the project in order to allow partial post processing of the results and only Applications Cases achievement were analysed in the last months of the project.

2 WORK PERFORMED

1.1 Overview of previous activities related to metrics

2.1.1 AGILE4.0 high-level goals

Within the Grant Agreement **Error! Reference source not found.**, AGILE 4.0 high level indicators that were identified are summarized as follows:

• each application case shall incorporate aspects of more than 2 supply-chain levels in their MDO workflows; metrics will be developed to assess this level of supply-chain involvement; [**Integrating the supply chain**]

• each application case shall demonstrate a 50% or more reduction in iterations between design and manufacturing phase; metrics will be developed to express the more effective transfer of information from design to manufacturing such as to avoid re-design iterations; [**Reduce in design iterations**]

• each application case shall consider 2 or more concurrent objectives that shall be addressed by multi-objective search methods to determine Pareto front of optimal solutions; metrics will be developed to express the level of multi-domain integration in the MDO workflows that are executed in the use cases; [**Trading in multiple objectives**]

• each application case shall demonstrate a 30% or more reduction in overall process development lead time due to the virtual integration of design, manufacturing and certification models; metrics will be developed to express the gains of the more efficient integrated virtual process development; **[Integrate virtual manufacturing, integrate virtual certification**]

• each application case shall demonstrate negligible time for collaborative MDO workflow reconfiguration; metrics will be developed to express the time needed to modify problem definition and/or involved tools in the considered collaborative MDO workflows. [**Reduce reconfiguration time**]

2.1.2 AGILE 4.0 steps

The high-level representation of AGILE 4.0 approach is presented in Fig. 1: Schema of the AGILE 4.0 steps.Fig. 1**Error! Reference source not found.** and summarized as follows (more details can be found in D-4.3 **Error! Reference source not found.**).

- The AGILE 4.0 approach starts with the I**dentification** step of system of interest. In this step, stakeholders and collection of their needs are conducted.
- Then, the **Specification** step is performed. Here, Concepts of Operations (ConOps) are elaborated to describe through scenarios how the system will operate during its life cycle and therefore to refine and validate stakeholder needs. Validated needs are then transformed into requirements.
- The next step concerns the **Architecting** phase. Requirements, produced in the preceding step, drive the system architecting and its development. Several potential solutions are defined by generating different system architectures made of different logical components, i.e. system components (e.g. engine, wing) that are not constrained to a particular technology.
- Then the **System Synthesis** is considered. In this step, conceptual designs are performed to derive potential and not optimized physical architectures of the System of Interest.
- Finally, the last step concerns the **Design & Optimization** phase. The various system physical architectures are finally designed and optimized through MDAO processes. Trade-off analyses are performed and decision-making techniques are adopted to eventually define the best solution.

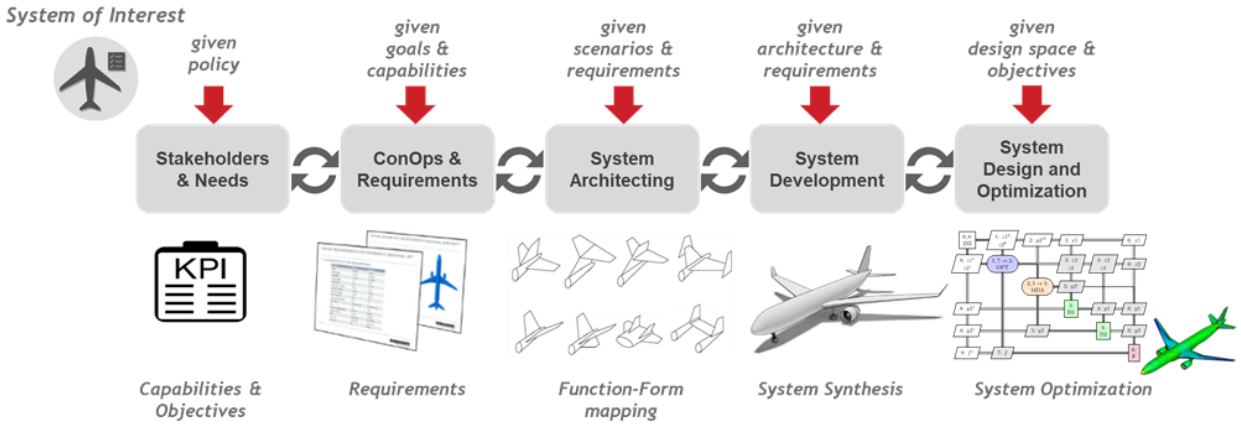


Fig. 1: Schema of the AGILE 4.0 steps.

2.1.3 AGILE 4.0 Application Cases

The ACs are representative of 3 main product development streams: production driven, certification driven and upgrade driven. A short recall of each AC goals is made below and more details about their achievements can be found in [1], [2] and [3].

2.1.3.1 Application Case 1: Flap design optimization for noise reduction and optimal manufacture

This AC is part of the production stream and aims at bringing manufacturing in the aircraft MDO workflow. The AGILE 4.0 MDO framework will be used for the design on 2 different concepts (drop-hinge and Manta concept). The two different solutions are characterized by different impact on aircraft performance (e.g. mass, aerodynamic efficiency) and different manufacturing processes.
The objective is to have the ability to select the best flap to produce by trading performance vs manufacturing costs and manufacturability.

2.1.3.2 Application Case 2: Horizontal tail design optimization including uncertainties due to supply chain issues

This AC is part of the production stream and aims at accounting Supply Chain in the aircraft MDO workflow. The AGILE 4.0 MDO framework will be used for the design of a horizontal tail plane (HTP) made by different materials. The different solutions are characterized by different impact on aircraft performance (e.g. mass, aerodynamic efficiency), different manufacturing processes and different combination of supply chains.
The objective is to have the ability to select the best HTP to produce by trading performance vs manufacturing costs vs supply chain performance

Fig. 2 provides an overview of the two application cases of the production stream.

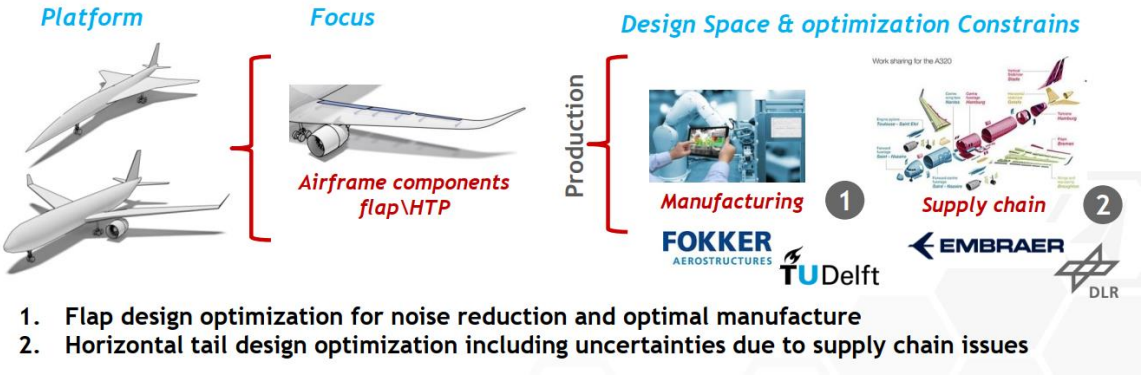


Fig. 2: Overview of production stream application cases

2.1.3.3 Application Case 3: Systems electrification

This AC is part of the certification stream and aims at accounting certification in the aircraft MDO workflow. The AGILE 4.0 MDO framework will be used for the design of a 19 PAX, regional turboprop aircraft with multiple on-board systems (OBS) architecture. These different solutions are characterized by increasing electrification with different impact on aircraft performance and on safety and reliability.
The objective is to have the ability to select the best OBS by trading performance vs certification time/cost.

2.1.3.4 Application Case 4: Maintenance Based Design'

This AC is part of the certification stream and aims at accounting maintenance in the aircraft MDO workflow. The AGILE 4.0 MDO framework will be used for the design of a 19 PAX, regional turboprop aircraft with multiple OBS architecture, with similar TLAR as AC3. These different solutions are characterized by increasing electrification with different impact on aircraft performance and maintainability.
The objective is to have the ability to select the best OBS by trading performance vs maintenance time/cost.

2.1.3.5 Application Case 5: Virtual Airframe

This AC is part of the certification stream and aims at accounting certification in a UAV MDO workflow. The AGILE 4.0 MDO framework will be used for the design of a UAV with the integration of airframe and OBS certification constraints, specifically Electro-Magnetic Compatibility (EMC) and heat management constraints. The different solutions are characterized by different impact on aircraft performance and different certification criteria.
The objective is to have the ability to select the best UAV by trading performance vs certification performance.

Fig. 3 provides an overview of the three application cases of the certification stream.

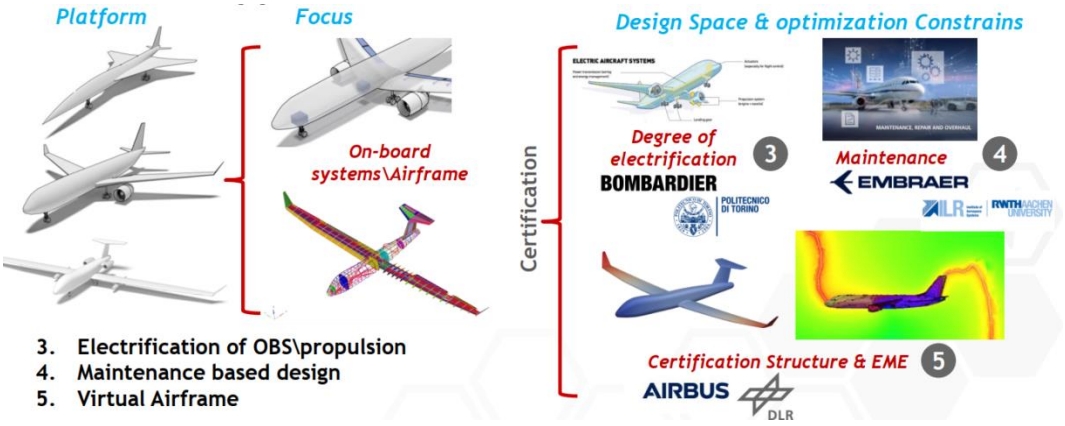


Fig. 3: Overview of certification stream application cases.

2.1.3.6 Application Case 6 Airframe upgrade design

This AC is part of the upgrade driven stream and aims at accounting retrofitting options in the aircraft MDO workflow. The AGILE 4.0 MDO framework will be used for the design on several retrofitting concepts (engine, OBS, winglet). The different solutions are characterized by different impact on aircraft performance (e.g. direct operating cost (DOC), emissions) and different retrofitting costs.
The objective is to have the ability to select the best retrofitting strategy to produce by trading DOC/emission vs retrofitting costs.

2.1.3.7 Application Case 7: Family concept design

This AC is part of the upgrade driven stream and aims at accounting commonality options in aircraft MDO workflow. The AGILE 4.0 MDO framework will be used for the design of 3 different aircraft with different commonality choices (wing, engine, Empennage). The different solutions are characterized by different impact on aircraft performance (e.g. mass, aerodynamic efficiency) and different commonality choices.
The objective is to have the ability to select the best family by trading performance vs commonality.

Fig. 4 provides an overview of the two application cases of the upgrade driven stream

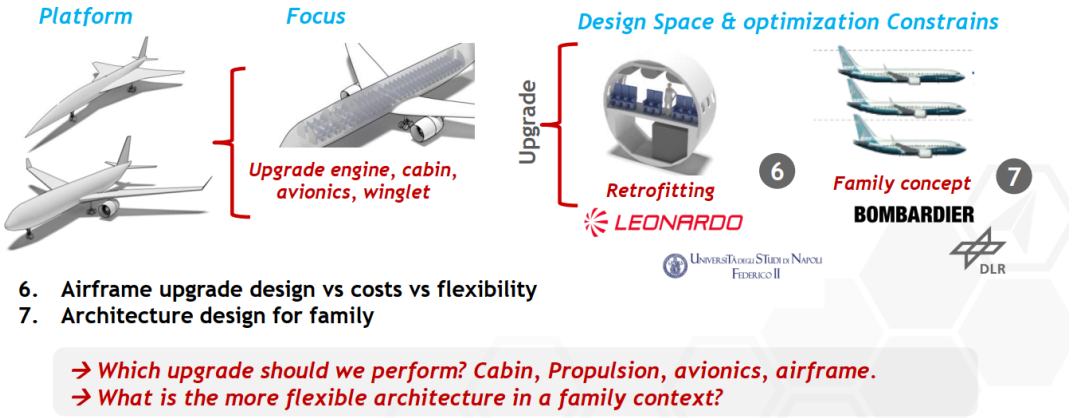


Fig. 4: Overview of upgrade driven stream application cases

2.1.4 Global relationships

This section aims at identifying the relationships between those 3 elements that will help defining the scope of metrics.

All the seven Application cases can be related to the AGILE 4.0 high-levels objectives as shown Fig. 5**Error! Reference source not found.**.

- AC1 and 2 will contribute to the **reduction of development time/cost** with the integration of virtual manufacturing and to the **increase of competitiveness** with the integration of virtual supply chain
- AC 3, 4 and 5 will contribute to the **reduction of development time** with the integration of virtual certification.
- All ACs will contribute to the **reduction of development time /cost** and the **increase of competitiveness** with the trading of multiple objectives and the reduction of design iterations.

Therefore, as the assessment of AGILE 4.0 objectives will be evaluated through the ACs achievements, the metrics should be related to each AC in order to measure its improvement.

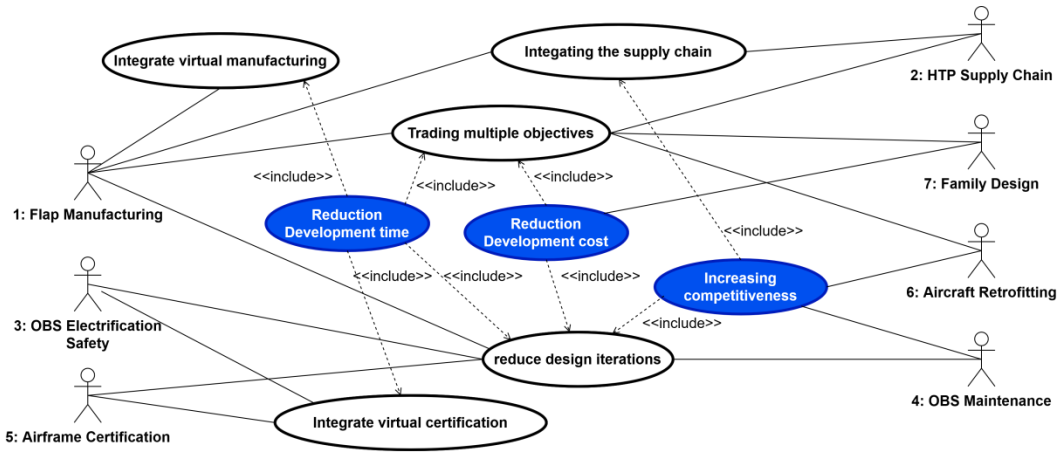


Fig. 5: Relationship between UCs scope and AGILE 4.0 high levels objectives

1.2 Metrics identification

As stated in [5] the metrics should be focusing on ACs evolution at AGILE 4.0 steps level. The retained metrics are of three kinds:

- The first set of metrics is targeting the System of interest and aims at measuring the degree of achievement of each Application Case regarding the challenges identified by AGILE 4.0 steps. These metrics will be hereafter called “challenges metrics” and will be evaluated by ACs owners from industry
- The second set of metrics is targeting the Development system and aims at measuring the degree of fulfillment of initial industry requirements regarding AGILE 4.0 framework. These metrics will be hereafter called “industry metrics” and will be evaluated by MBSE and MDO experts from industry
- The third set of metrics is targeting the combination of Development system and System of interest and aims at measuring the degree of improvement on the Application Case developments using the AGILE 4.0 framework. These metrics will be hereafter called “effectiveness metrics” and will be evaluated by ACs integrators from research

Fig. 6 recalls the layers considered in AGILE 4.0.

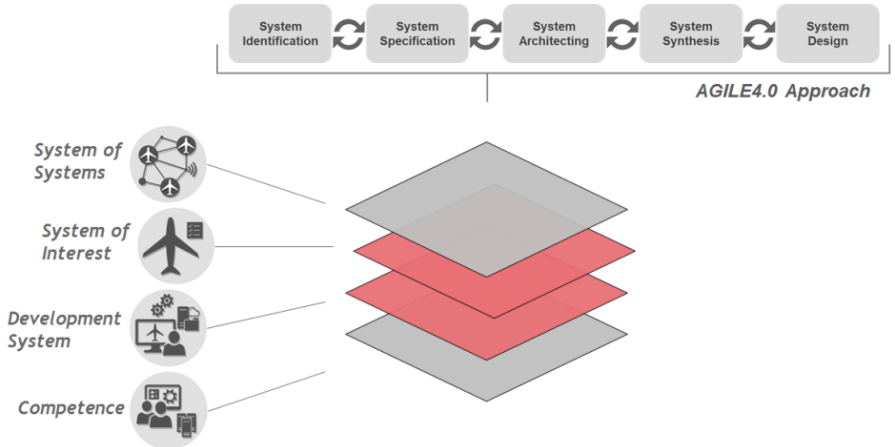


Fig. 6: AGILE 4.0 layers covered by metrics

Additional information about AGILE 4.0 Framework (A4F) and its implementation into the Collaborative Operational Environment (OCE) can be found in D4.10 [4].

1.2.1 ACs challenge metrics

1.2.1.1 Rational

These metrics are focusing on the system of interest of each AC. The objective of such metrics is to evaluate the achievements of each AC regarding the challenges identified in the AGILE 4.0 steps. Within Task 1.3, each AC owner and integrator has been asked to identify the challenges expected in each AGILE 4.0 phase and evaluate its degree of complexity. This degree of complexity is ranging from 1 to 5, 1 meaning "highly challenging" and 5 "mostly not challenging". The complexity can come from the lack of available data or models or/and from a large space to be explored in the step. The results for each AC are presented in [5] and are recalled in the figure below.

	Identification	Specification	Architecting	Synthesis	Design & Opt
AC1 flap					
AC2 supply chain					
AC3 electification safety					
AC4 electrification maintenance					
AC5 certification					
AC6 retrofitting					
AC7 family					

Fig. 7: Initial challenges per AC and per step identified at the beginning of AGILE 4.0

The metric associated to "challenge" is related to **Fulfillment.** Here we want to estimate to which extent each AC owner considers that each challenge is fulfilled. The metric is measured in rating format with options ranging from "Not fulfilled" to "Fully achieved", following the AGILE 4.0 steps. In addition, owners should indicate if they want to modify the challenge value and for which reason.

1.2.1.2 Process for collecting metrics

The retained process to collect the challenges metrics can be defined answering the following questions:

- *Who will provide the metrics values?* As written above, for these metrics we target the owners of each AC as they are responsible for the assessment of their AC.
- *How often will they be collected?* Here we want to assess the progress of the operational phase of the AC, therefore the right timing should be aligned with AGILE 4.0 roadmap. The feedback from the AC owners will be collected during the last phase of the project (M24-M36).
- *How will they be collected?* These metrics will be collected through the use of a Google form that will be adapted to each AC.

2.1.5 ACs industry metrics

2.1.5.1 Rational

These metrics are focusing on the development system of AGILE4.0. The objective of such metrics is to evaluate the achievements of each AC regarding the initial industry requirements regarding AGILE 4.0 framework.
Within WP1, industrial partners provide their expectations regarding the MBSE framework (including MDO expectations). Within WP1, AGILE 4.0 partners extracted the requirements and exchanges with industrial partners to check completeness and correctness of requirements. Within WP2, AGILE 4.0 partners connected requirements to the AGILE 4.0 techno's development. Within WP3, after and internal assessment process, aiming at classifying each requirement in terms of **levels of achievement**, the industrial partners will be asked to review and give a final mark.

2.1.5.2 Process for collecting metrics

The retained process to collect the industry metrics can be defined answering the following questions:

- *Who will provide the metrics values?* As written above, for these metrics we target the industry experts that provided the project with initial set of capabilities
- *How often will they be collected*? Here we want to assess the progress of the operational phase of the AC, therefore the right timing should be aligned with AGILE 4.0 roadmap. The feedback from the industry experts should be collected close to the end of the project.
- *How will they be collected?* These metrics will be collected through files exchanges and workshops

1.2.2 ACs effectiveness metrics

1.2.2.1 Rational

The objective of such metrics will be to evaluate the progress of all AC developments all along the project. Like the "challenges" metrics, these ones will also follow the AGILE 4.0 steps. Nevertheless, as far as implementation is concerned, these steps will be split in smaller ones, mapped on OCE development like indicated in **Error! Reference source not found.**.

AGILE 4.0 steps	Initial Sub steps
Identification **(stakeholders and neeeds)**	Define stakeholders and needs as separate instances in the context of the design study and relate needs to corresponding stakeholders
	Validation of stakeholders and needs models
	Visualization and inspect stakeholders and needs
	Quantify the "value" of the System of Interest
Specification (conops and requirements)	Identify and model operating scenarios to validate stakeholder needs.
	Enrich the use-case models with system requirements
	Verifiy requirements
	Visualize and inspect requirements
	Formulate of the MDAO problem from requirements
Architecting **(Sytem Architecting)**	Model the functionnal architecture
	Model system architecture design space
	Pre-select system architectures instance
	Visualize system architecture instance.
Synthesis **(System development)**	Generate an aircraft baseline with a determined architecture
	Connect architecture models to MDAO
	Visualize and inspect the geometry of the product under development
	Collect in a report the main data about the product under development
	Select the solution with the highest "value"
Design & Opt. **(System Design and Optimization)**	Formulate simulation workflow through connecting the systems models to the MDAO workflow, and specify the design competences
	Specify the MDAO architecture
	Visualize and inspect the MDAO process
	Access to optimization capabilities (RSM, optimizer)
	Execute workflow in a collaborative environnement
	Produce trade off studies
	Post-process of the simulation workflow results

*Tab. 1: Identification of AGILE 4.0 steps and sub-steps associated (see **Error! Reference source not found.**)*

These metrics associated to effectiveness are of 3 kinds and are described below:

- First metric is related to **Time**. Here we want to estimate the time that was needed for the AC integrator to achieve the activities performed in each AGILE 4.0 Framework (A4F) step. The aim of this metric is to identify the time spent on the activity in order to assess to which extent the OCE development enable to accelerate the development time of each AC. The metric will be measured in days, weeks and months.
- Second metric is related to **Easiness**. Here we want to estimate how easy it was for the AC integrator to achieve the activities performed in each A4F steps. The aim of this metric is to assess to which extent the OCE development eases the fulfillment of the required actions for this step. The metric will be measured in rating format with options ranging from "Really difficult" to "Everything was easy".
- Last metric is related to **Completeness**. Here we want to estimate to which extent each AC integrator managed to achieve all the planned activities performed in each A4F steps. The aim of this metric is to assess to which extent the OCE developments allow the user to fulfill his expectations. The metric will be measured in rating format with option ranging from: "I managed to cover less than 25 % of my expectations" to "I managed to cover everything I wanted to do".
-

2.1.5.3 Process for collecting metrics

The retained process to collect the effectiveness metrics can be defined answering the following questions:

- *Who will provide the metrics values?* As written above, for these metrics we target the integrators of each AC as they are responsible for for the deployment and implementation of the AC.
- *How often will they be collected?* Here we want to assess the progress the deployment of the AC, therefore, the right timing should be aligned with OCE release.
- *How will they be collected?* These metrics will be collected through the use of a Google form that will be adapted to each OCE release's capabilities but common to each AC.

2.2 Metrics results

2.2.1 Challenge metrics outcomes

2.2.1.1 Activities

As planned, the metrics were collected close to the end of the project, in order for all ACs to have successfully achieved tradeoffs activities and to allow the owners to evaluate the finalized achievements.

2.2.1.2 Detailed analysis

First, a review of the challenges scores have been asked to the ACs owners. Fig. 8 presents the evolution of challenges once all the ACs have been concluded.

	Identification	Specification	Architecting	Synthesis	Exploration
AC1 flap	+		+		+
AC2 supply chain	-	--			--
AC3 electification safety					
AC4 electrification maintenance					
AC5 certification	-		++		
AC6 retrofitting					
AC7 family					

Fig. 8: Updated challenges per AC and per step identified at the end of AGILE 4.0

One can note that, for most ACs, no evolution was indicated by the owners. For three ACs, the first steps were considered a bit easier than expected, mainly thanks to the OCE implementation. The architecting step was found more challenging for two ACs (AC1 and AC5). This is mainly due to the fact that all ACs were asked to consider the architecture of two systems of interest and their relationship. Regarding the Optimization step, the modification of the challenge level reflects how much harder (or easier) the optimization was found compared to expectations.

Then for each AGILE4.0 step, each owner was asked to what extent he considers this step to be fulfilled. As the degree of challenge can impact the measurement of fulfillment, the results, shown in Fig. 9 combine both information. The figure can be split in 4 quadrants:

- At bottom left, low level of challenge and low satisfaction, which corresponds to the worst feedback as one would expect the step to be easy to fulfill.
- At top left, low level of challenge and high satisfaction, which is an acceptable feedback
- At bottom right, high level of challenge and low satisfaction, which corresponds to a slightly better feedback than in the previous quadrant
- At top right, high level of challenge and high satisfaction, which corresponds to the highest possible feedback.

Upon reviewing the figures, it is satisfactory that none of the owners provided feedback indicating a low level of challenge and low satisfaction for any of the steps.
For the identification step, all owners found it to be quite challenging, and most of the feedback received indicated a medium to high level of satisfaction. Only one owner expressed feedback below medium satisfaction, which was due to the limitation of the number of needs considered in the AC.
Regarding the specification step, level of satisfaction is concentrated around “very” satisfying. This can be attributed to the lower level of challenge than the previous step.

The architecting step provided the highest improvement for all steps, with almost all feedback located in the top right quadrant. This step was considered challenging because it required tackling at least two systems of interest from two domains and successfully mixing them.
In contrast, the synthesis step had the lowest improvement, with no results seen in the top right quadrant. For most owners, this step focused on integrating new design competencies related to new domains that were primarily developed with industry. Therefore, they tended to consider that the AGILE 4.0 development was not as important as in other steps.
Regarding the design and optimization step, almost all owners found the step quite challenging, as it aimed to achieve multi-domain trade-offs. For some owners, enabling such complex optimization was considered "extremely" satisfying. However, a few owners expressed some limitations in terms of problem complexity, which limited the level of satisfaction.

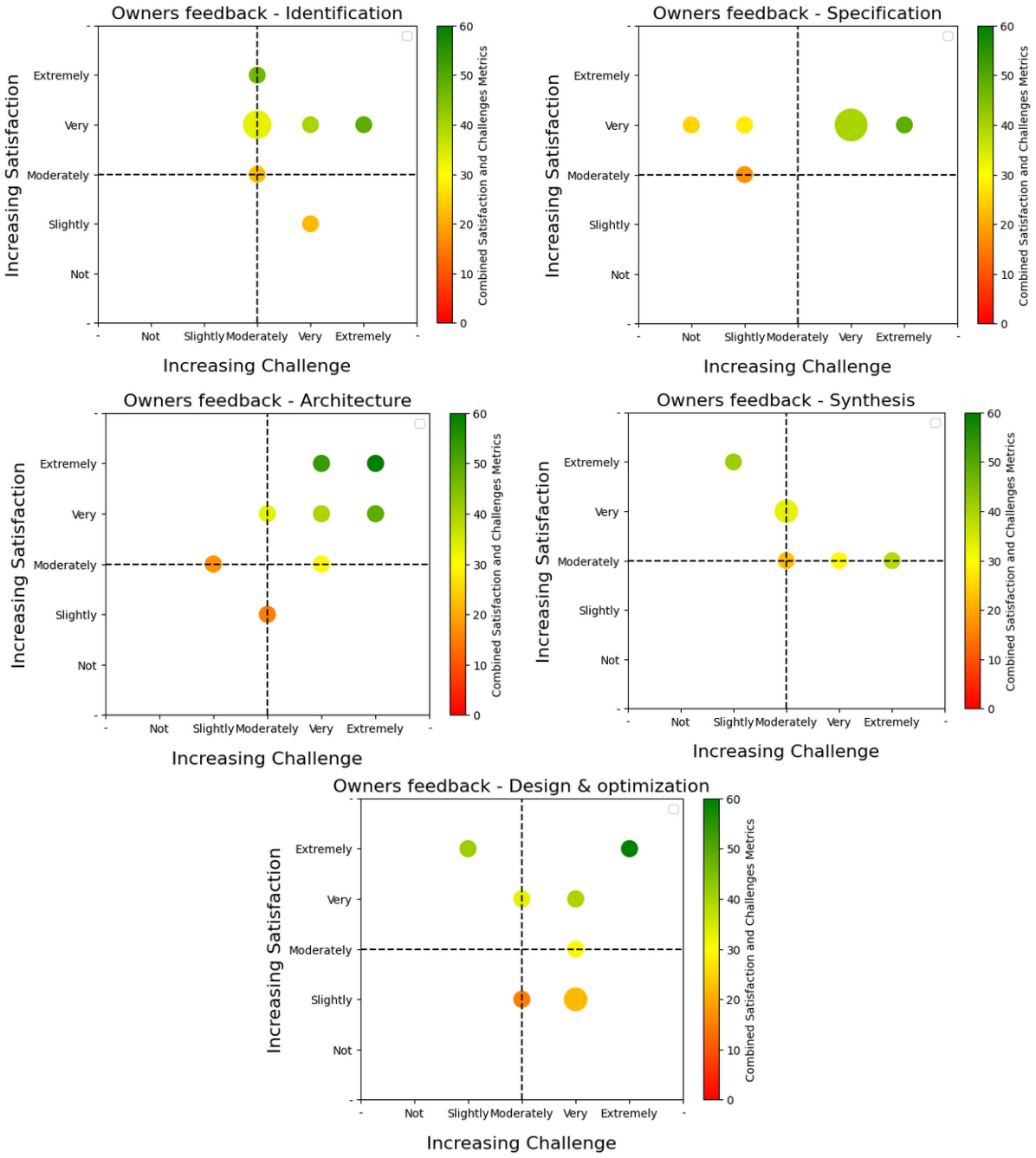


Fig. 9: Overview of AGILE 4.0 owners' feedback

Lastly, owners were asked to what extent they would reuse and/or integrate parts of AGILE4.0 into their own processes.
The results, depicted in Fig. 10, show that all owners are interested in reusing parts of AGILE4.0, but they are not interested in the same ones. The design competences developed in the project are the most likely outcomes to be reused. Since all ACs considered at least two domains, specific tools were developed or extended for "non-design" domains (such as manufacturing costs, retrofitting costs, etc.) that are of high interest for industrial partners. The methods developed and applied are also of interest for some owners, mainly concerning optimization approaches (such as for supply chain or family of aircraft) and optimizers. However, the integration of technos developed within the project appears to be less interesting for owners. This can be explained by the fact that, for most owners, the project aimed at exploring new approaches and gaining knowledge in closing the MBSE-MDAO bridge. Therefore, the integration of technos is expected but with a delay of a few years, around 2-3 years, as they would require additional development to be applied in the industry and comply, for instance, with data security policies. In line with this, direct reuse of the overall approach is not a high priority for most owners.

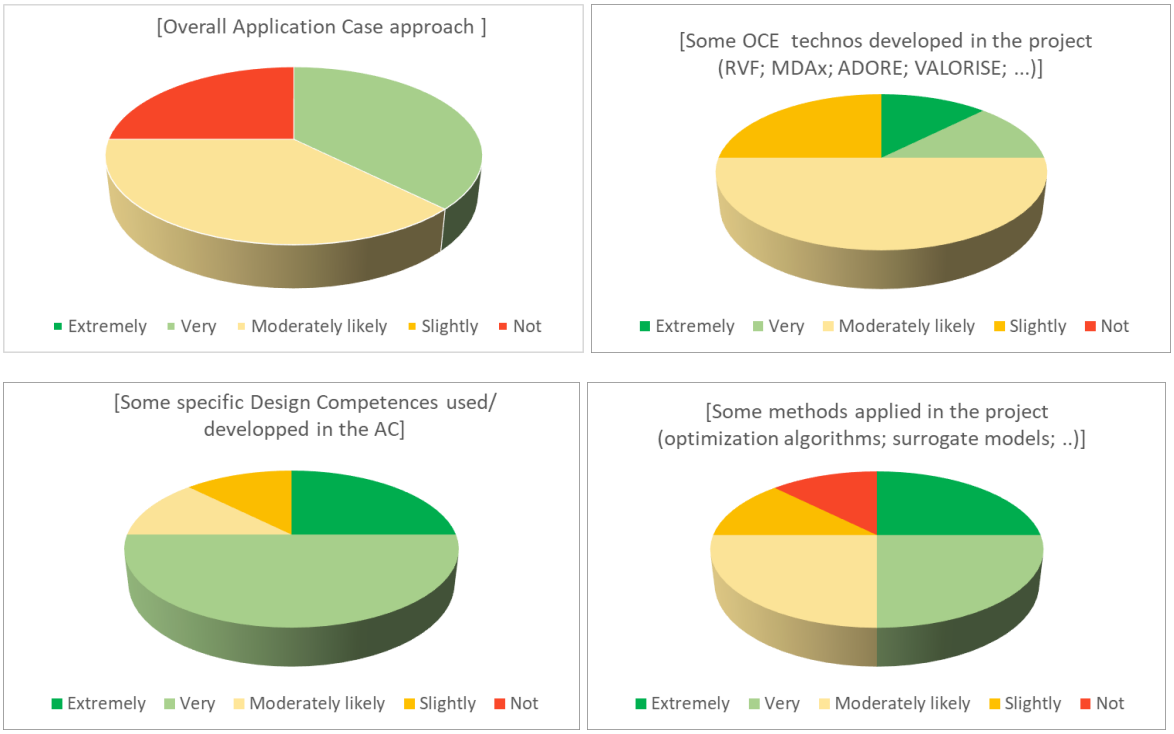


Fig. 10: Overview of AGILE 4.0 development re usability

As a conclusion, several feedback can be drawn from these challenge metrics analyses:

- Most of the activities performed within AGILE4.0 in terms of AC development were considered as challenging by ACs owners and most of the achievements were evaluated positively even though the level of satisfaction may vary between each step.
- All owners are interested in reusing parts of AGILE4. mainly design competences and methods. Even if the owners have interest in AGILE 4.0 technos, they acknowledge that it would require additional development to be compliant with industry standards.

2.2.2 Industry expert metrics outcomes

2.2.2.1 Activities

As described in 2.1.5.2, the industry expert metrics were the most complex task to fulfill regarding assessment process. During the last phase of the project, an internal assessment process was pursued in order to classify each requirement in terms of **levels of achievement.** In a second time, the industrial partners were asked to review the list and give a final mark. Unluckily, this last step took more time than expected and was not fully achieved by the end of the project. Nevertheless, the results obtained are presented in the next paragraph.

2.2.2.2 Detailed analysis

The following analysis highlights the main results of the internal assessment process for both MBSE and MDO framework requirements.
During this process, each requirement underwent a systematic verification process and was classified as either verified, partially verified, uncertain, not verified, or discarded. "Verified" means that the requirement has undergone a complete verification process. "Partially verified" means that the verification is achieved, but the scalability of the approach is not completely demonstrated. "Uncertain" is a more complex feedback, indicating that the internal assessment process has not managed to conclude and requires specific discussion with the requirement owner. "Not verified" is a clear statement indicating that the verification process cannot be fulfilled. Finally, "discarded" was added to highlight initial requirements that were not part of the project developments.
Concerning the MBSE parts, 63 requirements have been analysed and clustered into 3 different streams:

- **DEFINE** architectural elements (e.g. stakeholders, requirements, functions, components) at different levels of elaboration (i.e. system, subsystem, component) with 47 requirements
- **NAVIGATE** among all the elements of the system model, for traceability and impact assessments. Requirements include visualizations of the model according to viewpoints with 7 requirements
- **INTEGRATE**: these requirements address collaboration, re-usability, interoperability and management aspects of the system model with 9 requirements

Fig. 11 provides an overview of the main results. with more than 80 % of the MBSE requirements considered as verified or partially verified. Among “Not verified requirements”, one can highlight the absence of information pertaining to the dysfunctional behaviour (in terms of functional scenarios) and the lack of possible perspectives (in function of the person role).
The few remaining “Uncertain” requirements, are mainly related to the degree of interoperability of the AGILE 4.0 technos with other MBSE frameworks, as well as the adequacy of the viewpoints developed with the industry expectations.

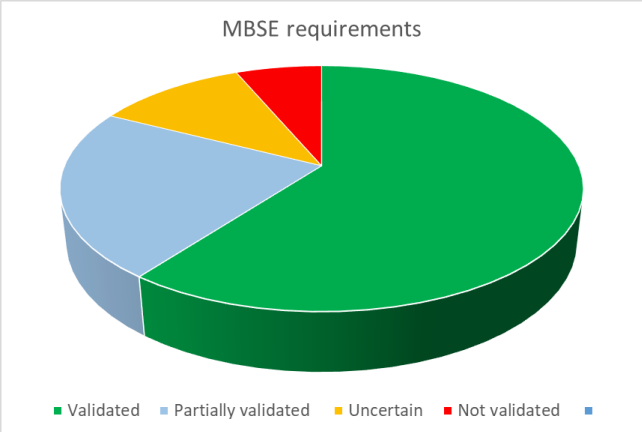


Fig. 11: Overview of MDO requirements status

Concerning the MDO parts, 58 requirements have been analysed and clustered into 2 different streams:

- Formulate and operate collaborative MDO with 35 requirements
- Access to MDO tools and methods (RSM, optimizer, etc.) with 14 requirements

Fig. 12 provides an overview of the main results with more than 60 % of the MDO requirements considered as verified or partially verified.
It is worth noting that the initial requirement list for MDO was not entirely tailored to the AGILE4.0 (and previous AGILE project) development. For instance, some requirements specific to high fidelity aero-structural topics were provided by the industry but were not part of the research, and these were discarded. After this, the percentage of verified or partially verified requirements increased to over 70%. Among the "Not verified" requirements were those that were envisioned for the project but not completed, such as uncertainties quantification and propagation.
The remaining "Uncertain" requirements were particularly interesting, mainly relating to the degree of interoperability between AGILE 4.0 technologies and other tools such as commercial software and other MDO frameworks. Additionally, there was a question about the level of automation required to access the latest RSM and optimization algorithms

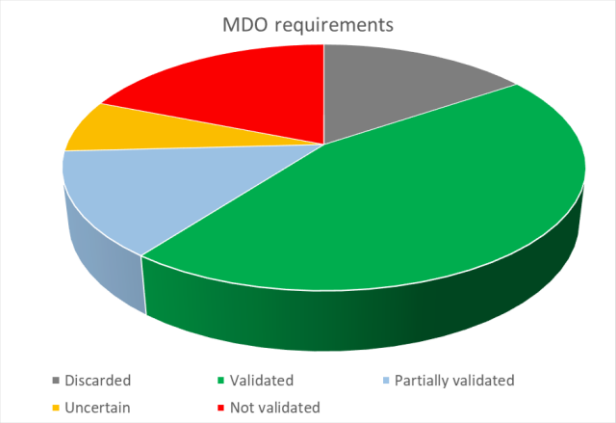


Fig. 12: Overview of MDO requirements status

As mentioned previously, the iterative verification process involving industry experts through data exchanges and dedicated workshops was unable to be completed within the project's timeframe. However, the feedback gathered during these exchanges suggested that the process was in line with expectations, and that the internal assessment process was consistent with preliminary feedback from industry.

As a conclusion, several feedback can be drawn from these industry metrics analyses:

- Starting form initial industry requirement regarding AGILE 4.0 framework, a systematic verification of the level of achievement has been conducted both for MBSE and MDO framework
- Regarding the MBSE framework, the achievement level reaches 80 % enabling to provide a very good coverage of initial expectations.
- Regarding the MDO framework, the achievement level reaches 70 % mainly because the MDO requirements covered a range wider than AGILE4.0 objectives.
- Remaining “not verified” requirements are well identified for both MBSE and MDO

2.2.3 Effectiveness metric outcomes

2.2.3.1 Activities

As described in 2.1.5.3, the metrics were collected at several times of the AGILE4.0 project, in accordance with the OCE version releases. The SOTA version of OCE was assessed in order to be used as a reference for the enhancements. Then, at every new major update of the OCE (i.e. every 6 months), the integrators were asked to fill in the form with a specific focus on new features implemented in OCE. This approach had several advantages in addition to the global assessment as it can also provide valuable information regarding learning curve and reconfigurability. For instance, any time a new capability is added to the OCE, one can measure the improvement brought to the overall process in terms of *completeness* but also the possible impact on *easiness* and *time* when using it for the first time. In addition, as this new capability might also be used again (for reconfiguration), improvements in the metrics for this step can be related to learning curve.
Fig. 13 provides an overview of the evolution of OCE capabilities since SOTA release.

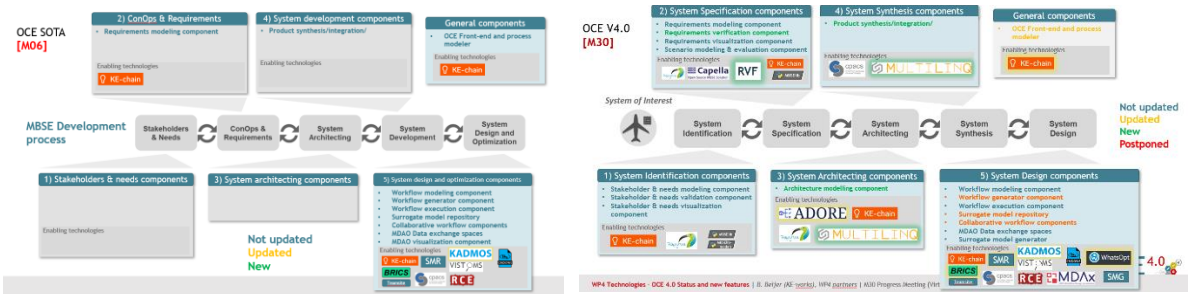
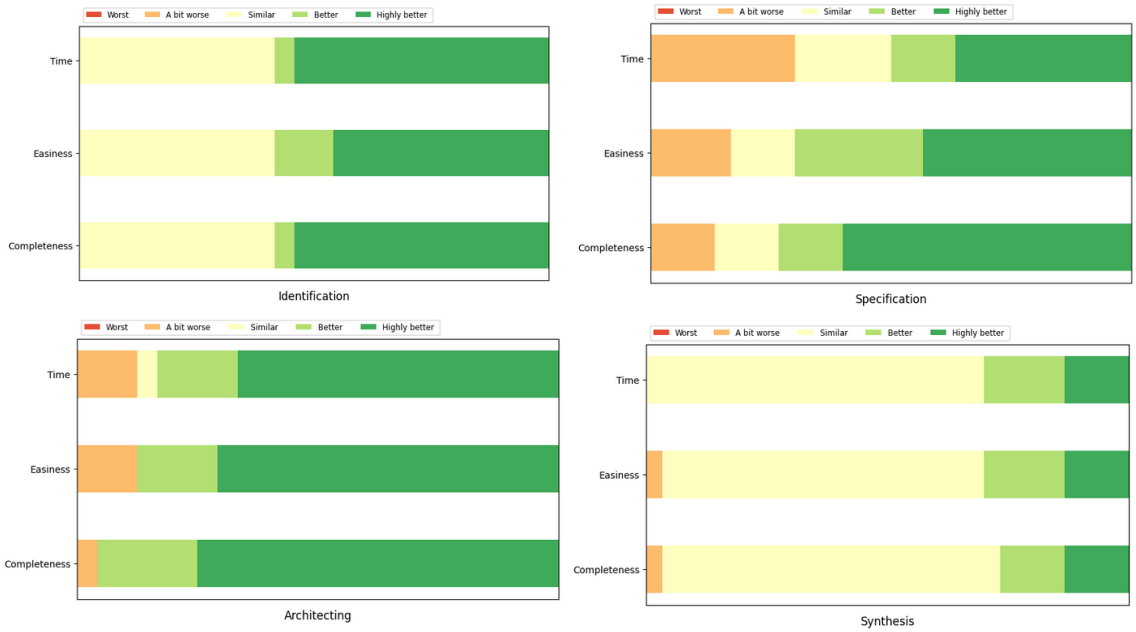


Fig. 13: Differences between OCE SOTA version and OCE4.0 version

2.2.3.2 Detailed analysis

The results are presented in terms of enhancement regarding the OCE SOTA version for each step and sub steps of AGILE4.0. The colormap is shown on Fig. 13 that aims at identifying whether there was an improvement or not and to which extent. This colormap is applied to the three aspects presented in section 1.2.2 namely *time*, *easiness* and *completeness*.



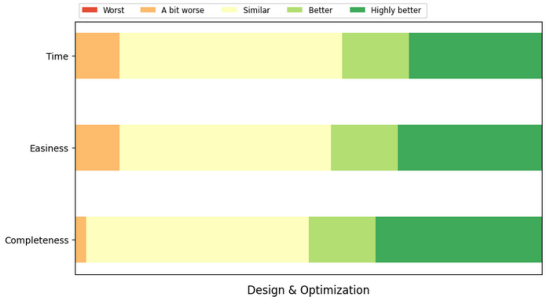


Fig. 14: Improvement between SOTA version and latest OCE release

Regarding the identification step, all three aspects showed an overall improvement, with some sub steps (mainly needs verification and visualization for which model-based approach is highly efficient) exhibiting “highly better” mark. The “Similar” mark observed corresponds to some activities not covered by OCE, namely the discussion among partners for stakeholders and needs identification.

Similarly, in the specification step, there was an overall improvement for all three aspects, although some sub-steps received a lower mark than the state-of-the-art (SOTA), particularly in the "Time" aspect. This was due to the scenario sub-step, which involved the use of Capella and was found to be difficult by the integrators. Like the identification step, the "Similar" mark observed corresponds to some activities not covered by OCE, namely the discussion among partners to specify the requirements. It's worth noting that the completeness metric, for this step - but also all the others – the highest one. Actually, all integrators agreed that, despite some sub-steps being more complex with a model-based approach, the overall completeness was always improved.

The architecting step showed the highest improvement across all the steps, with the majority of sub-steps showing a "highly better" mark. This was due to the introduction of technology to model architecture design space, select and visualize architecture instances, which brought significant improvement for all three aspects. Additionally, some integrators noted that technology like the ADORE tool could also be used for discussions among partners.

The synthesis step showed the smallest overall improvement, as several sub-steps covered were not implemented in the project, with partners relying on in-house code for results visualization and analysis. The enhancement responsible for the "highly better" mark corresponded to the sub-step "connect architecture models to the MDAO," which was a key achievement of the project.

Regarding the design and optimization step, it's important to remember that this was the main objective of the previous project, AGILE (2025-2018), and several technologies were already implemented at the start of the project. Nevertheless, further improvements were achieved, particularly in sub-steps such as the MDAO workflow specification, access to surrogate capabilities, and trade-off capabilities.

In conclusion, several feedback can be drawn from these effectiveness metrics analyses:

- There is global gain for all metrics for OCE modules, mainly due to the automation of activities and the enhanced capabilities brought by several techno developed during the project
- Every time a new techno is implemented, a learning phase is necessary, but once it is achieved, reconfiguration is quicker and easier
- Some activities corresponding to some sub steps (like identifying stakeholders and needs) are mainly done outside OCE but for some of them, using OCE technos is helpful in guiding the discussion
- Some room for improvement has been identified, especially in the post processing of the optimization results and the reporting of the analysis

Additional information about the lessons learnt can be found in deliverable D3.2 [5]

Finally, integrators provided feedback on the overall traceability along all the steps. As shown in Fig. 15, at the last release of OCE, all integrators agreed with all the traceability statements thus assessing one of the major objectives of the project.

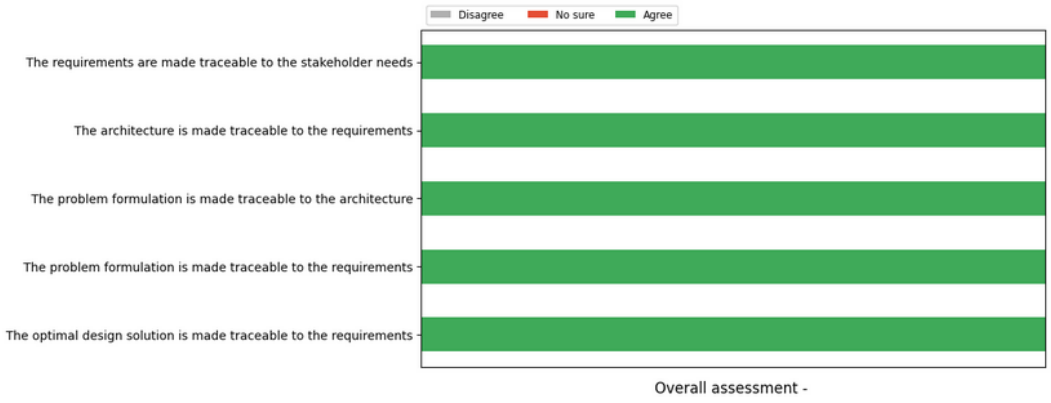


Fig. 15: Improvement between SOTA version and latest OCE release

2.3 Overall assessment

All the metrics collected in the previous section 2.2 contributed to the overall assessment of the project achievement as summarized in Table 1 : Overall assessmentTable 1.

High level goals	Detailed goal	Level	ACs	Results
Integrating the supply chain	each application case shall incorporate aspects of more than 2 supply-chain levels in their MDO workflows	System of interest	AC2	3 supply-chains levels have been successfully demonstrated
Reduce in design iterations	each application case shall demonstrate a 50% or more reduction in iterations between design and manufacturing phase	Development system	AC1, AC2	Overall traceability and architecture connection between design and manufacturing to achieve the objective
Trading in multiple objectives	each application case shall consider 2 or more concurrent objectives that shall be addressed by multi-objective search methods to determine Pareto front of optimal solutions	System of interest & Development system	All ACs	All ACs achieved 2 objectives optimizations (and sometimes more) between 2 domains
Integrate virtual manufacturing, integrate virtual certification	each application case shall demonstrate a 30% or more reduction in overall process development lead time due to the virtual integration of design, manufacturing and certification models	System of interest	AC1, AC2, AC3 and AC4	Increased automation of activities and capability to connect the different domains enabled to achieve the objective
Reduce reconfiguration time	each application case shall demonstrate negligible time for collaborative MDO workflow reconfiguration	System of interest & Development system	All ACs	Reconfiguration time range from less than an hour to a few.

Table 1 : Overall assessment

3 CONCLUSION AND OUTLOOK

In this Deliverable D3.4, a detailed discussion on the assessment activities of AGILE 4.0 technologies and Application Cases is provided, including a comprehensive overview of all proposed and collected metrics for both Development system and System of interest. The report also presents a systematic analysis of all the results, highlighting limitations and possible improvements.
Overall, the AGILE4.0 project has successfully developed an MBSE framework embedding the MDO process, meeting the initial industry requirements. The implementation of OCE has enabled a global gain in all metrics, including time, easiness, and completeness, through the automation of activities and integration of enhanced capabilities. The project has also achieved traceability along the development process. The Applications Cases proved to be challenging and relevant for the industry, providing positive outcomes in terms of the capabilities to consider and optimize complex and multi-domain problems, starting from stakeholder needs. All Applications Cases operated two multi-objective optimization workflows, achieving multiple trade-offs covering multiple domains.
These outcomes demonstrate the potential of the AGILE4.0 framework to support the efficient and effective development of complex systems, meeting the evolving needs of the industry.

4 REFERENCES

[1] WP6 partners, D6.5 *"Production driven stream MDO framework descriptions and trade of results, document"*, AGILE4.0 project

[2] WP7 partners, D7.5 *"Certification driven stream MDO framework descriptions and trade of results, document"*, AGILE4.0 project

[3] WP8 partners, D8.5 *"Upgrade driven stream MDO framework descriptions and trade of results, document"*, AGILE4.0 project

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[5] WP1 partners, D1.4 "Assessment metrics for AGILE 4.0 technologies", AGILE4.0 project

[6] WP3 partners, D3.2 "*Lessons learned. Best practices MDO collaborative framework"*, AGILE4.0 project